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Antitrust, Algorithmic Pricing and Tacit Collusion

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24. Antitrust, algorithmic pricing and tacit collusion

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I. INTRODUCTION

How competitive are our markets? Not as much as they ought to be. We are increasingly realizing the market failures and shortcomings of U.S. antitrust policy over the past 30 years. The White House in April 2016 issued an executive order and report on the state of competition in the U.S.[1] The report identified several disturbing signs about the decline in competition since the 1970s: First, competition appears to be decreasing in many economic sectors, including the decades-long decline in new business formation. The U.S. is seeing lower levels of firm entry and labor market mobility. Second, many industries are becoming more concentrated. Third, industry profits are increasingly falling into the hands of fewer firms. Basically, more industries are now dominated by fewer firms (increasing concentration). These few powerful firms are extracting greater profits (and wealth) from workers, sellers, and consumers. And it is getting harder for new firms to enter markets and for workers to change employers. Others, including the Economist,[2] the Atlantic,[3] and Harvard Business School,[4] have raised similar concerns.

The increased concentration and dampening of competition are not limited to our brick-and-mortar markets. Interestingly, and somewhat counterintuitively, certain online markets—where choice seems endless and competition fierce—have become more concentrated and less competitive.[5] One notable example of the implications of this increased concentration may be found in the European Commission's fining Google €2.42 billion for abusing its dominant position in search.[6] In addition, as *Virtual Competition*[7]

[1] Executive Order—Steps to Increase Competition and Better Inform Consumers and Workers to Support Continued Growth of the American Economy. Available online: https://obamawhitehouse.archives.gov/the-press-office/2016/04/15/executive-order-steps-increase-competition-and-better-inform-consumers.

[2] *The superstar company – A giant problem* https://www.economist.com/news/leaders/21707210-rise-corporate-colossus-threatens-both-competition-and-legitimacy-business; *Data is giving rise to a new economy* The Economist (6 May 2017) https://www.economist.com/news/briefing/21721634-how-it-shaping-up-data-giving-rise-new-economy.

[3] *America's Monopoly Problem* https://www.theatlantic.com/magazine/archive/2016/10/americas-monopoly-problem/497549/.

[4] *How competitive is America? How can we improve?* http://www.hbs.edu/competitiveness/Pages/default.aspx.

[5] https://www.wsj.com/articles/can-the-tech-giants-be-stopped-1500057243.

[6] European Commission – Press Release, Antitrust: Commission fines Google €2.42 billion for abusing dominance as search engine by giving illegal advantage to own comparison shopping service, Brussels, 27 June 2017.

[7] Ariel Ezrachi and Maurice E. Stucke, *Virtual Competition – The Promise and Perils of the Algorithm-Driven Economy* (HUP 2016).

and *Big Data and Competition Policy*[8] explore, technology, big analytics and big data—just as they are essential for dynamic competition—have been increasingly used to curtail competition.

Big data and the development of sophisticated computer algorithms and artificial intelligence are neither good, bad, nor neutral. Their nature depends on how firms employ them, and whether their incentives are aligned with our interests, and certain market characteristics. At times, big data and big analytics—in enhancing information flows and access to markets—can promote competition and our welfare. However, we cannot uncritically assume that we will always benefit.

This chapter explores some of the means through which algorithms and artificial intelligence may be used to dampen competition. We note how algorithmic pricing could, under certain market conditions, lead to conscious parallelism and higher prices. We explore how neural networks to monitor and determine price could take us further away from a "true" market price and the enforcement challenges raised by algorithmic tacit collusion.

II. THE COLLUSION SCENARIOS

Cartels are generally regarded in the antitrust world as "no-brainers." The cartel agreement, even if unsuccessful, is typically condemned as per se illegal. The price-fixers have few, if any, legal defenses. And in the United States, among other jurisdictions, the guilty executives are often thrown into jail. So what happens to cartels with the rise of pricing algorithms? Industries are migrating from the brick-and-mortar pricing environment (where store clerks once stamped prices on products) to dynamic, differential pricing where sophisticated computer algorithms rapidly calculate and update prices. Does that spell the end of cartels, or does it create new ways to collude?

Some argue the former. Cartels are often more durable than neoclassical economic theory predicts. Why? Humans often trust one another. "Collusion is more likely," the U.S. Department of Justice noted, "if the competitors know each other well through social connections, trade associations, legitimate business contacts, or shifting employment from one company to another."[9] Computers do not exhibit trust. Instead, algorithms engage in cold, profit-maximizing calculations. Even if they could agree with or trust other computers, they would find ways to cheat.

While not trusting, pricing algorithms—in increasing the speed of communicating price changes, detecting any cheating or deviations, and punishing such deviations—can *facilitate* existing forms of collusion and *foster new elusive forms of collusion*, achieved through subtler means, which do not amount to a hard-core cartel, and are beyond the law's reach.

We consider five scenarios in which computer algorithms may promote horizontal collusion[10]:

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8 Maurice E. Stucke and Allen P. Grunes, *Big Data and Competition Policy* (OUP 2016).

9 *Price Fixing, Bid Rigging, and Market Allocation Schemes: What They Are and What to Look For* https://www.justice.gov/atr/price-fixing-bid-rigging-and-market-allocation-schemes.

10 Pricing and price-monitoring algorithms can also foster vertical price-fixing (which is also called minimum resale price maintenance), whereby the manufacturer and retailer agree on

- The first scenario, *messenger*, concerns humans agreeing to collude and using computers to execute their will. One 2015 case involved posters sold through Amazon Marketplace:

> *The conspirators used commercially available algorithm-based pricing software, which continually collects competitor pricing information and prices a product based on a set of rules implemented by the seller. In order to match prices, one conspirator, with the agreement of the other, programmed its algorithm to find the lowest-price offered by a non-conspiring competitor for a particular poster, and then set its poster price just below that, and another conspirator set its algorithm to match the first conspirator's price. By agreeing to fix prices for certain posters, the conspirators eliminated competition among themselves for these sales. Such competition would have likely driven the poster prices down further. The conspirators monitored the effectiveness of their pricing algorithms by spot checking prices, and enforced their price-fixing agreement. Once the pricing algorithms were in place, however, the conspiracy was, to a large extent, self-executing.*[11]

  Under this scenario, humans collude. They use computers to assist in creating, monitoring, and policing a cartel. In the U.S. and elsewhere, they go to jail if caught.
- Our second scenario, *hub and spoke*, is more challenging. Here we consider the use of a single pricing algorithm to determine the market price charged by numerous users. Uber illustrates this framework. Uber drivers do not compete among themselves over price; some drivers might be willing to offer you a discount, but Uber's algorithm determines your base fare and when, where, and for how long to impose a surcharge. This, by itself, is legal. But as the platform's market power increases, this cluster of similar vertical agreements may beget a classic hub-and-spoke conspiracy, whereby the algorithm developer, as the hub, helps orchestrate industry-wide collusion, leading to higher prices.[12] Likewise, as the European Commission and

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the product's retail price. Manufacturers can use algorithms to detect deviations from a fixed or minimum resale price, "retaliate against retailers that do not comply with pricing recommendations and, therefore, limit the incentives of retailers to deviate from such pricing recommendations in the first place." Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 2 (14 June 2017). Vertical price-fixing may foster tacit collusion among competitors. As the Commission noted, "when retailer A adheres to fixed or minimum resale prices (RPM) and is being monitored by retailer B using algorithms, retailer B may match A's price. In this way, one retailer's use of RPM may spread high prices to other retailers who may not be similarly engaged in RPM." *Id*. at 2–3.

[11] Algorithms and Collusion – Note by the United States, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)41, at 2 (26 May 2017); *see also* https://www.justice.gov/atr/case/us-v-david-topkins.

[12] Opinion of Advocate General Szpunar delivered on 11 May 2017 in Case C 434/15, *Asociación Profesional Elite Taxi v Uber Systems Spain SL*, at n. 23 (noting that "the use by competitors of the same algorithm to calculate the price is not in itself unlawful, but might give rise to hub-and-spoke conspiracy concerns when the power of the platform increases"); *Meyer v. Kalanick*, 174 F. Supp. 3d 817, 822–27 (S.D.N.Y.) (finding that plaintiffs plausibly alleged a hub-and-spoke conspiracy in which drivers sign up for Uber precisely on the understanding that the other drivers were agreeing to the same pricing algorithm, and in which drivers' agreements with Uber would be against their own interests were they acting independently), *reconsideration denied in part*, 185 F. Supp. 3d 448 (S.D.N.Y. 2016).

United States, among others, noted, if competitors were to outsource their pricing decisions to the same third party, this would also raise antitrust concerns.[13]

- The third scenario, *the predictable agent*, is even more challenging. Here there is no agreement among competitors. Each firm unilaterally adopts its pricing algorithm, which sets its own price. So we shift from a world where executives expressly collude in smoke-filled hotel rooms to a world where pricing algorithms act as predictable agents and continually monitor and adjust to each other's prices and market data. The result, we explore, is algorithm-enhanced conscious parallelism—or, as we call it, tacit collusion on steroids.
- In the fourth collusion scenario, *digital eye*, we consider how two technological advancements can amplify tacit collusion, creating a new level of stability and scope. The first advancement involves computers' ability to process high volumes of data in real time to achieve a God-like view of the marketplace. The second advancement concerns the increasing sophistication of algorithms as they engage in autonomous decision making and learning through experience—that is, the use of artificial intelligence. These two technological advances enable a wider, more detailed view of the market, a faster reaction time in response to competitive initiatives, and dynamic strategies achieved by "learning by doing." Thus they can expand tacit collusion beyond price, beyond oligopolistic markets, and beyond easy detection. With the first three scenarios, we may know when something is amiss. In the fourth scenario, the contagion spreads to markets less susceptible to tacit collusion under the brick-and-mortar economy and beyond pricing to other competitive initiatives. In the end, with *digital eye* we may think the markets, driven by these technologies, are competitive. We may believe that tacit collusion in these markets isn't even possible. And yet we're not benefiting from this virtual competition.
- In the fifth *hybrid collusion/discrimination* scenario, algorithmic tacit collusion and behavioral discrimination can occur simultaneously in markets where conditions for both exist in various segments of the market. Sellers, for example, tacitly collude for the "low value" and loyal customers and behaviorally discriminate for the "high value" customers. The seller seeks to lure the "high value" buyers with personalized discounts. Once the hook is lodged (i.e., the customer's loyalty is established and

[13] Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 7 (14 June 2017); Algorithms and Collusion – Note by the United States, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)41, at 6 (26 May 2017) ("if competing firms each entered into separate agreements with a single firm (for instance a platform) to use a particular pricing algorithm, and the evidence showed they did so with the common understanding that all of the other competitors would use the identical algorithm, that evidence could be used to prove an agreement among the competitors that violates U.S. antitrust law"). But if the competitors independently and unknowingly adopted the same or similar pricing algorithms, this would "unlikely to lead to antitrust liability even if it makes interdependent pricing more likely." Algorithms and Collusion – Note by the United States, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)41, at 6 (26 May 2017). An interesting issue is whether the competitors would be liable if they intentionally but unilaterally adopted the same algorithm knowing that this would make interdependent pricing more likely.

control over outside options is achieved), the seller profits by offering the cheapest individualized inducement to secure the greatest profits.

III. CONDITIONS FOR ALGORITHMIC TACIT COLLUSION

Having outlined the five scenarios, let us focus on the key driver behind the third and fourth scenarios—which may enable rivals to increase price, through tacit collusion, without infringing the antitrust laws.

The emerging consensus among competition authorities is that algorithms can facilitate and enhance tacit collusion. Tacit collusion is where you have an anticompetitive outcome (namely higher prices) without any illegal agreement among competitors.[14] A classic example, as *Virtual Competition* explores, is where the gasoline stations on Martha's Vineyard raised prices above competitive levels without evidence of their colluding. As the OECD noted:

> Economic theory suggests that there is a considerable risk that algorithms, by improving market transparency and enabling high-frequency trading, increase the likelihood of collusion in market structures that would traditionally be characterised by fierce competition. . .[A]lgorithms might facilitate tacit co-ordination, a market outcome that is not covered by competition law, by providing companies with automated mechanisms to signal, implement common policies, as well as monitor and punish deviations. We also emphasise how algorithms can make tacit collusion more likely not only in oligopolistic markets with high barriers to entry and a high degree of transparency but also in markets where traditionally tacit collusive outcomes would be difficult to achieve and sustain over time, widening the scope of the so-called "oligopoly problem."[15]

As the OECD recognizes, algorithmic tacit collusion will spread, but it will not occur in every industry. Let us outline the conditions generally necessary for tacit collusion and the way algorithms could enhance its stability.

First, algorithmic tacit collusion would likely arise in concentrated and transparent markets involving homogenous products where the algorithms can monitor to a sufficient

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[14] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 17 (16 May 2017) (noting that tacit collusion "refers to forms of anti-competitive co-ordination which can be achieved without any need for an explicit agreement, but which competitors are able to maintain by recognising their mutual interdependence. In a tacitly collusive context, the non-competitive outcome is achieved by each participant deciding its own profit-maximising strategy independently of its competitors"); *Brooke Group Ltd. v. Brown & Williamson Tobacco Corp.*, 509 U.S. 209 (1993) (describing "the process, not in itself unlawful, by which firms in a concentrated market might in effect share monopoly power, setting their prices at a profit-maximizing, supracompetitive level by recognizing their shared economic interests and their interdependence with respect to price and output decisions and subsequently unilaterally set their prices above the competitive level"); R.S. Khemani and D.M. Shapiro, "Glossary of Industrial Organisation Economics and Competition Law". Paris Organisation for Economic Co-operation and Development, 1993, available at http://www.oecd.org/dataoecd/8/61/2376087.pdf.

[15] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 5 (16 May 2017).

degree the pricing and other keys terms of sale.[16] Conscious parallelism would be facilitated and stabilized by the shift of many industries to online pricing, as sellers can more easily monitor competitors' pricing, key terms of sale and any deviations from current equilibrium.[17] As the OECD observed:

> The increase of market transparency is not only a result of more data being available, but also of the ability of algorithms to make predictions and to reduce strategic uncertainty. Indeed, complex algorithms with powerful data mining capacity are in a better place to distinguish between intentional deviations from collusion and natural reactions to changes in market conditions or even mistakes, which may prevent unnecessary retaliations.[18]

Software may be used to report and take independent action when faced with price deviation, be it from the supra-competitive or recommended retail price.

A *second* important market condition is that once deviation (e.g., discounting) is detected, a credible deterrent mechanism exists.[19] Unique to an algorithmic environment is the speed of retaliation.[20] Computers can rapidly police deviations, and calculate the profit implications of myriad moves and counter-moves to punish deviations.[21] The speed

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[16] Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 8 (14 June 2017); Guidelines on the assessment of horizontal mergers under the Council Regulation on the control of concentrations between undertakings (2004/C 31/ 03), para 41. But as the OECD observed, "one peculiar aspect of algorithms is that it makes the number of competitors in the market a less relevant factor for collusion. In traditional markets, collusion is more easily sustainable if there are few competitors, as it is easier to find terms of co-ordination, to monitor deviations and implement effective punishment mechanisms among fewer firms. Algorithms can allow co-ordination, monitoring and punishment to take place also in less concentrated markets as their ability and speed in collecting and analysing data makes the number of firms to monitor and agree with less relevant. In other words, the small number of firms is an important but not a necessary condition for algorithmic collusion to take place." Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 19 (16 May 2017).

[17] Algorithms and Collusion – Note from Singapore, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)24, at 2 (31 May 2017).

[18] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 20 (16 May 2017).

[19] Guidelines on the assessment of horizontal mergers under the Council Regulation on the control of concentrations between undertakings (2004/C 31/ 03), para 41 [EC Merger Guidelines]; Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 8 (14 June 2017) (noting that "tacit collusion requires effective retaliation, which in turn requires spare capacity" as a "capacity-constrained firm cannot initiate a price war as a means of retaliation to enforce tacit collusion").

[20] Contrast this with EC Merger Guidelines, *supra* note 19, para 53 ("The speed with which deterrent mechanisms can be implemented is related to the issue of transparency. If firms are only able to observe their competitors' actions after a substantial delay, then retaliation will be similarly delayed and this may influence whether it is sufficient to deter deviation.").

[21] Jill Priluck, *When Bots Collude* The New Yorker (25 April 2015), available at http://www.newyorker.com/business/currency/when-bots-collude.

of calculated responses effectively deprives discounting rivals of any significant sales. The speed also means that the tacit collusion can be signalled in seconds. The greater the improbability that the first-mover will benefit from its discounting, the greater the likelihood of tacit collusion.[22] Thus if each algorithm can swiftly match a rival's discount and eliminate its incentive to discount in the first place, the "threat of future retaliation keeps the coordination sustainable."[23]

A *third* condition is that "the reactions of outsiders, such as current and future competitors not participating in the coordination, as well as customers, should not be able to jeopardize the results expected from the coordination."[24] Thus algorithmic tacit collusion will likely arise in concentrated markets where buyers cannot exert buyer power (or entice sellers to defect), sales transactions tend to be "frequent, regular, and relatively small,"[25] and the market in general is characterized by high entry barriers.

A *fourth* condition is that tacit collusion is more profitable than competition. The algorithm, in maximizing profits, "would need to decide that it is a better course of action than competitive pricing, especially if competitive pricing leads to drastically larger sales volumes."[26]

A *fifth* condition involves the super-platform's incentives. Firms may operate off a particular platform, such as Amazon's for shopping or Google's or Apple's mobile operating system for apps. As the Italian competition authority discussed:

> either directly or indirectly, online platforms define the "rules of the game", thereby affecting firms' incentives to adopt certain pricing strategies rather than others. Any attempt to an intra-platform collusion may fail in presence of fierce inter-platform online competition: therefore, it will be important to understand the impact of pricing algorithms considering both intra-platform and inter-platform online competition.[27]

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[22] Samuel B. Hwang and Sungho Kim, "Dynamic Pricing Algorithm for E-Commerce", in Tarek Sobh and Khaled Elleithy (eds.), *Advances in Systems, Computing Sciences and Software Engineering, Proceedings of SCSS05* (Springer 2006) 149–55; N. Abe and T. Kamba, *A Web Marketing System with Automatic Pricing* 33 Computer Networks 775–88 (2000); L.M. Minga, Y.Q. Fend, and Y.J. Li, *Dynamic Pricing: E-Commerce-Oriented Price Setting Algorithm* 2 International Conference on Machine Learning and Cybernetics (2003).

[23] EC Merger Guidelines, *supra* note 19, para 52; Algorithms and Collusion – Note from Singapore, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)24, at 2 (31 May 2017).

[24] EC Merger Guidelines, *supra* note 19, para 41.

[25] US Horizontal Merger Guidelines 2006, available at https://www.justice.gov/atr/file/801216/download.

[26] Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 8 (14 June 2017). As the OECD noted, "market stagnation characterised by declining demand and the existence of business cycles may hinder collusion. This is because firms have strong incentives to profitably deviate when demand is high and reducing the costs of retaliation in future periods when demand is low." Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 20 (16 May 2017).

[27] Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 3 (2 June 2017).

The stability needed for algorithmic tacit collusion is enhanced by the fact that algorithms are unlikely to exhibit many biases when setting prices.[28] Human biases, of course, may be reflected in the programming code. But biases will not necessarily affect decisions on a case-by-case basis: a computer does not fear detection and possible financial penalties or incarceration; nor does it respond in anger.[29] "We're talking about a velocity of decision-making that isn't really human," said Terrell McSweeny, a commissioner with the U.S. Federal Trade Commission. "All of the economic models are based on human incentives and what we think humans rationally will do. It's entirely possible that not all of that learning is necessarily applicable in some of these markets."[30]

When the above conditions are present, tacit collusion is likelier. To be clear, no bright line exists when an industry becomes sufficiently concentrated for either express or tacit collusion.[31] Generally, for illegal cartels involving *express* collusion which were detected and prosecuted, the empirical research has found that cartels involving a trade association were on average over twice as large than cartels without a trade association involved.[32]

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[28] EC Merger Guidelines, *supra* note 19, para 44 (observing that "[c]oordination is more likely to emerge if competitors can easily arrive at a common perception as to how the coordination should work. Coordinating firms should have similar views regarding which actions would be considered to be in accordance with the aligned behaviour and which actions would not."); Algorithms and Collusion – Note from Singapore, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)24, at 2 (31 May 2017).

[29] M. Stucke and A. Ezrachi, *How Pricing Bots Could Form Cartels and Make Things More Expensive* Harvard Business Review (27 October 2016), available at https://hbr.org/2016/10/how-pricing-bots-could-form-cartels-and-make-things-more-expensive.

[30] David Lynch, *Policing the Digital Cartels* Financial Times (9 January 2017), available at http://www.pros.com/about-pros/news/financial-times-policing-digital-cartels/.

[31] Note, for example, research by Levenstein and Suslow, who offer several explanations for the lack of a clear empirical relationship between industry concentration and cartels involving express collusion: "First, this ambiguity may reflect the bias introduced by focusing on cartels that were prosecuted by the U.S. Department of Justice; cartels with large numbers of firms or that had the active involvement of an industry association may have been more likely to get caught. Second, industries with a very small number of firms may be able to collude tacitly without resort to explicit collusion. Third, concentration is endogenous: collusion may have allowed more firms to survive and remain in the market." Margaret C. Levenstein and Valerie Y. Suslow, *What Determines Cartel Success?* 44(1) Journal of Economic Literature 43–95 (2006).

[32] One empirical analysis of successfully prosecuted cartels between 1910 and 1972 showed that cartels on average had many participants: where a trade association facilitated collusion, 33.6 firms was the mean of firms involved, and fourteen firms was the median; in price-fixing cartels (without a trade association involved), 8.3 firms was the mean and six was the median. Arthur G. Frass and Douglas F. Greer, *Market Structure and Price Collusion: An Empirical Analysis* 26 J. Indus. Econ. 21, 25, 36–41 (1977). One conservative assumption in that empirical study was that the number of cartel members prosecuted reflected the total number of firms in the relevant market. (*Id.* at 24). But, aside from ineffectual fringe firms, the relevant market may contain more participants than reflected in the government's indictment or criminal information, which does not always identify all the co-conspirators. Consequently, the authors had to exclude from its sample of 606 cases, those cases where the number of firms allegedly involved were not specified in the records (*Id.* at 25–26). Some co-conspirators conceivably could escape prosecution (through lack of evidence). Although the authors rely upon an earlier study, which showed a 0.959 correlation between the number of conspirators and total number of firms in the market, the sample size of that earlier study was 34 cases (*Id.* at 28, citing George Hay and Daniel Kelly, *An Empirical Survey of Price Fixing Conspiracies* 17 J.L. and Econ. 13 (1974).) For studies of cartels immunized from

The belief is that express collusion generally represents the outer boundary. (Otherwise why would competitors expressly collude when they could tacitly collude legally?) One maxim is that tacit collusion is "frequently observed with two sellers, rarely in markets with three sellers, and almost never in markets with four or more sellers."[33] Whether this is empirically true is another matter.[34]

Even if we accept the premise that tacit collusion is likelier in duopolies than triopolies and quadropolies, two factors should give us pause: One factor is that the state of competition in major economies, like the United States, is worrisome, with evidence of increasing concentration and greater profits flowing into fewer hands.[35] Thus, if market concentration increases, more markets may be susceptible to tacit collusion. A second factor is that the industry-wide use of algorithms, given the speed and enhanced transparency, could expand the range of industries susceptible to collusion beyond duopolies to perhaps markets dominated by five or six players, as we illustrate below.

Ultimately, we are likely to see more instances in which similar pricing is not the result of fierce competition, nor the result of cartel activity, but rather the result of algorithmic tacit collusion. While competitors may use different technologies or algorithms, their incentive is to avoid price wars and embed a stabilizing, profit-maximizing strategy in their algorithms.

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the antitrust laws, see, e.g., Andrew R. Dick, *Identifying Contracts, Combinations & Conspiracies in Restraint of Trade* 17 Managerial and Decision Econ. 203, 213 (1996) (discussing that cartels are formed more frequently in unconcentrated industries under Webb-Pomerene Export Trade Act); see also Paul S. Clyde and James D. Reitzes, *The Effectiveness of Collusion Under Antitrust Immunity: The Case of Liner Shipping Conferences, Bureau of Economics Staff Report* (Dec. 1995) (finding a positive, but economically small, relationship between overall market concentration and shipping rates), available at https://www.ftc.gov/sites/default/files/documents/reports/effectiveness-collusion-under-antitrust-immunity-case-liner-shipping-conferences/232349.pdf; *see also* Maurice E. Stucke, *Behavioral Economists at the Gate: Antitrust in the Twenty-First Century* 38 Loy. U. Chi. L.J. 513, 555–56 (2007) (collecting earlier empirical work on cartels in moderately concentrated and unconcentrated industries); *id*. at 58 (finding no simple relationship between industry concentration and likelihood of collusion); Margaret C. Levenstein and Valerie Y. Suslow, *Breaking Up Is Hard to Do: Determinants of Cartel Duration* 54 J.L. and Econ. 455 at 12 (finding international cartels prosecuted between 1990–2007 had on average 7.4 members).

[33] J. Potters and S. Suetens, *Oligopoly experiments in the current millennium* 27(3) Journal of Economic Surveys 439–60 (2013).

[34] Niklas Horstmann, Jan Kraemer, and Daniel Schnurr, *Number Effects and Tacit Collusion in Experimental Oligopolies* (24 October 2016), available at SSRN: https://ssrn.com/abstract=2535862 or http://dx.doi.org/10.2139/ssrn.2535862 (finding from the extant literature "no robust empirical evidence that would support this claim of a strictly monotonic relationship between the number of firms and the degree of tacit collusion in a given market," but finding this monotonic trend from their own two experiments).

[35] *See, e.g.*, Jonathan B. Baker, 'Market power in the U.S. economy today' (March 2017); Economic Innovation Group, 'Dynamism in Retreat: Consequences for Regions, Markets, and Workers' (February 2017); Gustavo Grullon, Yelena Larkin, and Roni Michaely, 'Are US Industries Becoming More Concentrated?' (Feb 23, 2017), available at SSRN: https://ssrn.com/abstract=2612047 or http://dx.doi.org/10.2139/ssrn.2612047; Germán Gutiérrez and Thomas Philippon, 'Declining Competition and Investment in the U.S.' NBER Working Paper No. 23583 (July 2017), http://www.nber.org/papers/w23583.

IV. RECENT EXAMPLES

Companies are increasingly using pricing algorithms. As the European Commission found in its 2016 e-commerce sector inquiry:

> About half of the retailers track online prices of competitors. In addition to easily accessible online searches and price comparison tools, both retailers and manufacturers report about the use of specific price monitoring software, often referred to as "spiders", created either by third party software specialists or by the companies themselves. This software crawls the internet and gathers large amounts of price related information. 67% of those retailers that track online prices use (also) automatic software programmes for that purpose. Larger companies have a tendency to track online prices of competing retailers more than smaller ones. . .some software allows companies to monitor several hundred online shops extremely rapidly, if not in real time. . .Alert functionalities in price monitoring software allow companies to get alerted as soon as a retailer's price is not in line with a predefined price.[36]

As the Italian competition authority observed, "a number of specialized software developers offer solutions than allow even small companies to implement 'strategic' dynamic pricing strategies, offering tools to 'auto-detect pricing wars' as well as to 'help drive prices back up across all competition.'"[37]

To illustrate, let us consider the use of online pricing in an oligopolistic retail market for petrol. Two recent economic studies explored how the increased transparency resulting from posting petrol prices online, and the use of pricing algorithms, have fostered conscious parallelism. In Chile, petrol stations were required in 2012 to post their fuel prices on a government website and to keep prices updated as they changed at the pump. An economic study found that this Chilean regulation softened, rather than increased, competition.[38] The petrol stations' margins increased by ten percent on average following the prices being posted on the government website. Similarly, in Germany, the government required petrol stations to report any price changes for gasoline or diesel fuel in "real time."[39] The enhanced market transparency, an economic study found, increased prices further. Compared to the control group, retail petrol prices increased by about 1.2 to 3.3 euro cents, and diesel increased by about two euro cents.[40]

Another "enhancement" may be found in the emergence of "hub-and-spoke" structures

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[36] Brussels, 15.9.2016 SWD(2016) 312, Paras 550–51, http://ec.europa.eu/competition/antitrust/sector_inquiry_preliminary_report_en.pdf.

[37] Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 3 (2 June 2017).

[38] Fernando Luco, *Who Benefits from Information Disclosure? The Case of Retail Gasoline*, Working Paper, Department of Economics, Texas A&M University (28 September 2016), available at http://dx.doi.org/10.2139/ssrn.3186145.

[39] *Fuel Sector Inquiry,* Final Report by the Bundeskartellamt (May 2011), available at http://www.bundeskartellamt.de/SharedDocs/Publikation/EN/Sector%20Inquiries/Fuel%20Sector%20Inquiry%20-%20Final%20Report.pdf?__blob=publicationFile&v=14; Ralf Dewenter, Ulrich Heimeshoff, and Hendrik Lüth, *The Impact of the Market Transparency Unit for Fuels on Gasoline Prices in Germany* (May 2016), available at http://www.dice.hhu.de/fileadmin/redaktion/Fakultaeten/Wirtschaftswissenschaftliche_Fakultaet/DICE/Discussion_Paper/220_Dewenter_Heimeshoff_Lueth.pdf.

[40] *Id.*

in our online environment. The term "hub and spoke" is often used in antitrust to discuss conspiracies, aimed at competitors' *expressly* fixing the price or facilitating cartel activities. Our focus is different. We note how in an online environment a hub-and-spoke framework may emerge as sellers use the same third-party provider for algorithmic pricing, or the same data pool to determine price.

The use of the same "hub" for determining pricing of products and services may further stabilize the market. It could reduce the number of "decision makers" and further facilitate tacit collusion. One recent example is the petrol market in Rotterdam. As the Wall Street Journal reported, the Dutch petrol stations used advanced analytics and AI provided by the Danish company, a2i Systems, to determine their petrol prices.[41] Retail petrol prices dropped, at times, to reflect less demand. But during some periods

> the stations' price changes paralleled each other, going up or down by more than 2 U.S. cents per gallon within a few hours of each other. Often, prices dropped early in the morning and increased toward the end of the day, implying that the A.I. software may have been identifying common market-demand signals through the local noise.[42]

The software operated by a2i Systems is focused primarily on modeling consumer behavior and learns when raising prices drives away customers and when it does not.[43] In a case study found on its website, a2i Systems discussed how it helped OK Benzin, Denmark's leading petrol station owner, avoid a price war: "Between 2007 and 2012 the market was characterized by fierce competition and high volatility. At the peak there were 10 to 20 price changes a day, and the spread between the highest and the lowest price of the day could be up to 15 eurocent."[44] In enlisting a2i Systems, the leading retail network of approximately 700 petrol stations (which accounted for 25 percent of the Danish retail fuel market), sought "to improve the pricing analysis and decision process and optimize pricing according to their overall strategy in order to lower the cost of price wars or better yet, to avoid them."[45]

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41 Sam Schechner, *Why Do Gas Station Prices Constantly Change? Blame the Algorithm* Wall Street Journal (18 May 2017), available at https://www.wsj.com/articles/why-do-gas-station-prices-constantly-change-blame-the-algorithm-1494262674.

42 *Id.*

43 Schechner, *supra* note 41. See also the company website: "PriceCast Fuel utilizes Artificial Intelligence (AI) to optimally reach the local and/or global target for any given station and product. By continuously monitoring data (such as transactions, competitors' prices, time, location, traffic, weather, etc.) PriceCast Fuel learns about customers' and competitors' behaviors and optimizes the price for each product at each site, taking every significant correlation into account." Available at http://a2isystems.com/pricecast.html#pricecast-fuel-19.

44 PriceCast Fuel Case Story, available at http://a2isystems.com/files/pdf/PriceCast%20Fuel%20Case%20Story%20('15).pdf.

45 *Id.*

V. ENFORCEMENT POLICY

The EU and some U.S. policymakers have acknowledged over the past two years algorithmic tacit collusion as an antitrust concern. The European Commission, noted that, among other things,

> increased price transparency through price monitoring software may facilitate or strengthen (both tacit and explicit) collusion between retailers by making the detection of deviations from the collusive agreement easier and more immediate. This, in turn, could reduce the incentive of retailers to deviate from the collusive price by limiting the expected gains from such deviation.[46]

The French and German competition authorities similarly noted in a joint report that:

> Even though market transparency as a facilitating factor for collusion has been debated for several decades now, it gains new relevance due to technical developments such as sophisticated computer algorithms. For example, by processing all available information and thus monitoring and analysing or anticipating their competitors' responses to current and future prices, competitors may easier be able to find a sustainable supra-competitive price equilibrium which they can agree on.[47]

Likewise, the U.K. House of Lords noted how the rapid developments in data collection and data analytics have created the potential for new welfare reducing and anti-competitive behavior, including new forms of collusion.[48] The Italian competition authority observed how the "widespread usage of algorithms could also pose possible anti-competitive effects by making it easier for firms to achieve and sustain collusion."[49] And the OECD in 2016 commented that these strategies "may pose serious challenges to competition authorities in the future, as it may be very difficult, if not impossible, to prove an intention to coordinate prices, at least using current antitrust tools."[50]

In 2017, the Russian competition authority initiated dawn raids of LG Electronics Rus Ltd., Philips Ltd. and Sangfiy SES Electronics Rus Ltd. after receiving complaints on concerted actions of these enterprises in the sales of equipment.[51] The Russian Federation believes that "an increase in the number of algorithms used for setting

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[46] Para. 608, Commission Staff Working Document accompanying Commission Final report on the E-commerce Sector Inquiry. (10 May 2017) COM(2017) 229 final. Also note the European Commission investigations into online sales practices launched on 2 February 2017. As part of the investigation into consumer electronics manufacturers the Commission will also consider the effects of pricing software that automatically adapts retail prices to those of leading competitors.

[47] 2016 joint report, *Competition Law and Data*, Page 14, with reference to our earlier work – Artificial intelligence and collusion: when computers inhibit competition. http://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Berichte/Big%20Data%20Papier.pdf?__blob=publicationFile&v=.

[48] Paras. 178 and 179, https://www.publications.parliament.uk/pa/ld201516/ldselect/ldeucom/129/12908.htm

[49] Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 2 (2 June 2017).

[50] Para 81: Big Data: Bringing Competition Policy To The Digital Era, DAF/COMP(2016)14 (27 Oct. 2016), https://one.oecd.org/document/DAF/COMP(2016)14/en/pdf.

[51] Algorithms and Collusion – Note by the Russian Federation, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)22, at 4 (15 May 2017).

prices can help create longer-term cartels that are less obvious to traditional regulators using traditional methods of proving violations, which inter alia can negatively affect consumers."[52]

Why are competition enforcers concerned about algorithmic tacit collusion? The fear is that we have significant harm (namely higher prices), without any liability or direct remedy.[53] Tacit algorithmic collusion, in many countries, would likely escape antitrust scrutiny. To prosecute collusion, enforcers typically require proof of an agreement among competitors to tamper with prices, allocate markets, etc. As the OECD noted, "Although there is great variance in how jurisdictions interpret the notion of agreement, they traditionally require some sort of proof of direct or indirect contact showing that firms have not acted independently from each other (the so-called 'meeting of the minds')."[54] With tacit collusion (conscious parallelism), there is not any agreement. Instead each competitor acts unilaterally, in response to the behavior of competitors. As discussed earlier, that unilateral strategy, in concentrated, transparent markets with homogeneous products, will likely result in higher prices. The concern among competition officials is that tacit collusion—as more industries rely on pricing algorithms—will spread. Importantly, the nature of online markets, the availability of data, the development of similar algorithms, and the stability and transparency they foster, will likely push some markets that were just outside the realm of tacit collusion into interdependence.[55] If algorithmic tacit collusion spreads from duopolies to markets with four, five or six competitors, the competition authority still "might experience increasing difficulties in qualifying the infringement, finding evidence and determining antitrust liability."[56]

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[52] Algorithms and Collusion – Note by the Russian Federation, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)22, at 2 (15 May 2017).

[53] Marc Ivaldi, Bruno Jullien, Patrick Rey, Paul Seabright, and Jean Tirole, 'The Economics of Tacit Collusion', Final Report for DG Competition (Toulouse: European Commission, March 2003), available at http://ec.europa.eu/competition/mergers/studies_reports/the_economics_of_tacit_collusion_en.pdf.

[54] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 17 (16 May 2017).

[55] One would expect tacit collusion to be feasible with a larger number of participants than commonly assumed. On the common market assumptions, see generally R. Selten*, A Simple Model of Imperfect Competition, Where Four Are Few and Six Are Many* 2 International Journal of Game Theory 141 (1973); Steffen Huck, Hans-Theo Normann, and Jörg Oechssler, *Two Are Few and Four Are Many: Number Effects in Experimental Oligopolies* 53(4) Journal of Economic Behavior and Organization 435–46 (2004).

[56] See, e.g., Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 4 (2 June 2017).

VI. LEGALITY OF ALGORITHMIC TACIT COLLUSION

Under most jurisdictions' antitrust laws, the unilateral use of algorithms to monitor and set price is legal, even if it leads to prices above competitive levels.[57] After all, one cannot condemn a firm for behaving rationally and interdependently on the market.[58]

When the algorithms increase market transparency, defendants will often have an independent legitimate business rationale for their conduct. Courts and the enforcement agencies may be reluctant to restrict this free flow of information in the marketplace. Although the exchange of current or future pricing, sales, and output information among themselves can subject competitors to antitrust liability,[59] the general belief is that increasing the transparency of the market (by posting the actual price and key terms of sale) makes the market more efficient. "The dissemination of information," the U.S. Supreme Court observed, "is normally an aid to commerce"[60] and "can in certain circumstances increase economic efficiency and render markets more, rather than less, competitive."[61] Indeed, concerted action to reduce price transparency may itself be an antitrust violation.[62]

Accordingly, "pure" forms of tacit collusion which result from a unilateral rational reaction to market characteristics would not normally trigger antitrust liability. On the other hand, intervention may be triggered when an illicit concerted practice "contaminated" or "facilitated" the conscious parallelism. In some instances, enforcers can question whether the rivals acted unilaterally. At times, either a horizontal or vertical agreement may be inferred. Condemned actions may include signaling, exchange of information, agreement to engage in common strategy, manipulation through the sharing of data pools and other collusive strategies.

57 Rational unilateral reaction to market dynamics (free from agreements or communications) in itself, is legal under EU and US competition law. As noted earlier, tacit collusion does not amount to concerted practice and therefore escapes Article 101 TFEU. Tacit collusion may serve to establish Collective Dominance under Article 102 TFEU, but absent a separate abuse, it will also escape scrutiny under this provision.

58 See, for example, Case C-199/92, *P Hüls AG v. Commission*, [1999] ECR I-4287, [1999] 5 CMLR 1016; Joined Cases C-89, 104, 114, 116, 117, 125, 129/85, *Ahlström Osakeyhtiö and others v. Commission (Wood Pulp II)*, [1993] ECR I-1307, [1993] 4 CMLR 407; Cases T-442/08, *CISAC v Commission*, [2013] 5 CMLR 15 (General Court).

59 *Am. Column & Lumber Co. v. United States*, 257 U.S. 377, 397 (1921).

60 *Sugar Institute, Inc. v. United States*, 297 U.S. 553, 598 (1936).

61 *United States v. United States Gypsum Co.*, 438 U.S. 422, 441 n.16 (1978); see also Richard A. Posner, *Antitrust Law* 2nd ed. (University of Chicago Press 2001) 160.

62 See, for example, Federal Trade Commission, Funeral Directors Board Settles with FTC (16 August 2004), http://www.ftc.gov/opa/2004/08/vafuneral.htm (a board's prohibition on licensed funeral directors advertising discounts deprived consumers of truthful information); Federal Trade Commission, Arizona Automobile Dealers Association, FTC C-3497 (February 25, 1994) (a trade association illegally agreed with members to restrict nondeceptive comparative and discount advertising and advertisements concerning the terms and availability of consumer credit); Organisation for Economic Co-operation and Development, Price Transparency, DAFFE/CLP(2001)22 (September 11, 2001), 183, 185–86 (citing examples of U.S. enforcement agencies seeking to increase price transparency); compare *InterVest, Inc. v. Bloomberg, L.P.*, 340 F.3d 144 (3d Cir. 2003) (lack of price transparency in bond market not illegal if consistent with unilateral conduct).

The European Commission noted this distinction:

> one could argue that through repeated interactions, two firms' pricing algorithms could come to "decode" each other, thus allowing each one to better anticipate the other's reactions. However, the case-law is clear that Article 101 "does not deprive economic operators of the right to adapt themselves intelligently to the existing and anticipated conduct of their competitors". . .Short of signalling. . .it is therefore not obvious that more sophisticated tools through which a firm merely observes another firm's price and draws its own conclusion would qualify as "communication" for Article 101 purposes. At the same time, at this stage, one cannot fully rule out the possibility that more creative and novel types of interactions could in certain situations meet the definition of "communication".[63]

In February 2017, the Commission announced an investigation into the possible breach of EU competition law by Asus, Denon & Marantz, Philips and Pioneer. Among other things, the Commission was appraising whether the companies restricted the "ability of online retailers to set their own prices for widely used consumer electronics products such as household appliances, notebooks and hi-fi products." According to the Commission:

> The effect of these suspected price restrictions may be aggravated due to the use by many online retailers of pricing software that automatically adapts retail prices to those of leading competitors. As a result, the alleged behaviour may have had a broader impact on overall online prices for the respective consumer electronics products.[64]

The Commission in 2018 fined the companies, after finding the four manufacturers used sophisticated monitoring tools to intervene when online retailers offered their products at low prices, below the level requested by the manufacturers. The use of sophisticated monitoring tools allowed the manufacturers to effectively track resale price setting in the distribution network and to intervene swiftly in case of price decreases.

Antitrust intervention is easier when algorithms are part of a wider collusive agreement to tamper with market prices.[65] Similarly, weaker forms of signaling, aimed at coordinating practice of the market could be condemned.

But, the question remains: should "pure" forms of tacit collusion be condemned? Ought we condemn the facilitation of tacit collusion through artificial means? Should one condemn a firm for behaving rationally and developing, unilaterally, an algorithm that takes into account publicly available information while operating interdependently on the market?[66]

One way to square this circle may be framing the issue as market manipulation or an unfair practice. The focus shifts from the presence of an agreement among companies

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63 Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 8 (14 June 2017) (citation omitted).

64 http://europa.eu/rapid/press-release_IP-17-201_en.htm.

65 See for example: Topkins, https://www.justice.gov/opa/pr/former-e-commerce-executive-charged-price-fixing-antitrust-divisions-first-online-marketplace.

66 See, for example, Case C-199/92, *P Hüls AG v. Commission*, [1999] ECR I-4287, [1999] 5 CMLR 1016; Joined Cases C-89, 104, 114, 116, 117, 125, 129/85, *Ahlström Osakeyhtiö and others v. Commission (Wood Pulp II)*, [1993] ECR I-1307, [1993] 4 CMLR 407; Cases T-442/08, *CISAC v Commission*, [2013] 5 CMLR 15 (General Court).

to the use of advanced algorithms to transform pre-existing market conditions in such a way to facilitate tacit collusion. While the mutual price monitoring at the heart of tacit collusion is legal, one may ask whether the creation of such a market dynamic, through "artificial" means, gives rise to antitrust liability.

Using such an approach, one could consider application of legislation such as Section 5 of the FTC Act, which targets unfair facilitating practices.[67] Noteworthy is how the U.S. courts set a rather high level of intervention. Under the legal standard applied in *Ethyl*,[68] the Federal Trade Commission must show either (1) evidence that defendants tacitly or expressly agreed to use pricing algorithms to avoid competition, or (2) oppressiveness, such as (a) evidence of defendants' anticompetitive intent or purpose or (b) the absence of an independent legitimate business reason for the defendants' conduct.[69] Accordingly, defendants may be liable if, when developing the algorithms or in seeing the effects, they were (1) motivated to achieve an anticompetitive outcome, or (2) aware of their actions' natural and probable anticompetitive consequences.

An alternative route may target "abuse" of excessive transparency, possibly where clear anticompetitive intent is present. One could employ the rationale used in the U.S. Securities and Exchange Commission's (SEC) case against Athena Capital Research.[70] In 2014, the SEC for the first time sanctioned the high-frequency trading firm for using complex computer programs to manipulate stock prices.[71] The sophisticated algorithm, code-named *Gravy*, engaged in a practice known as "marking the close" in which stocks were bought or sold near the close of trading to affect the closing price: "[t]he massive volumes of Athena's last-second trades allowed Athena to overwhelm the market's available liquidity and artificially push the market price—and therefore the closing price—in Athena's favor."[72] Athena's employees, the SEC alleged, were "acutely aware of the price impact of its algorithmic trading, calling it 'owning the game' in internal e-mails."[73]

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[67] The FTC was unsuccessful in its attempt to prove such facilitating practices in *Boise Cascade Corp. v. F.T.C.*, 637 F.2d 573 (9th Cir. 1980) and *E. I. du Pont de Nemours & Co. v. F.T.C.*, 729 F.2d 128 (2d Cir. 1984).

[68] *E. I. du Pont de Nemours & Co. v. F.T.C.*, 729 F.2d 128 (2d Cir. 1984).

[69] *Id.* at 128, 139.

[70] U.S. Securities and Exchange Commission, Administrative Proceeding File No. 3-16199 (October 16, 2014), http://www.sec.gov/litigation/admin/2014/34-73369.pdf.

[71] The computer trading program was "placing a large number of aggressive, rapid-fire trades in the final two seconds of almost every trading day during a six-month period to manipulate the closing prices of thousands of NASDAQ-listed stocks." U.S. Securities and Exchange Commission, SEC Charges New York–Based High Frequency Trading Firm with Fraudulent Trading to Manipulate Closing Prices, October 16, 2014, http://www.sec.gov/News/PressRelease/Detail/PressRelease/1370543184457#.VEOZlfldV8E. *Id.*

[72] *Id.*

[73] *Id.* As the SEC alleged Athena's manipulative scheme focused on trading in order to create imbalances in securities at the close of the trading day: "Imbalances occur when there are more orders to buy shares than to sell shares (or vice versa) at the close for any given stock. Every day at the close of trading, NASDAQ runs a closing auction to fill all on-close orders at the best price, one that is not too distant from the price of the stock just before the close. Athena placed orders to fill imbalances in securities at the close of trading, and then traded or 'accumulated' shares on the continuous market on the opposite side of its order." According to the SEC's order, Athena's algorithmic strategies became increasingly focused on ensuring that the firm was the dominant firm—and sometimes the only one—trading desirable stock imbalances at the end of each trading

Athena employees "knew and expected that *Gravy* impacted the price of shares it traded, and at times Athena monitored the extent to which it did. For example, in August 2008, Athena employees compiled a spreadsheet containing information on the price movements caused by an early version of *Gravy.*"[74] Athena configured its algorithm *Gravy* "so that it would have a price impact."[75] In calling its market-manipulation algorithm *Gravy*, and by exchanging a string of incriminating e-mails, the company did not help its case. Without admitting guilt, Athena paid a $1 million penalty. This demonstrates that automated trading has the potential to increase market transparency and efficiency, but it can also lead to market manipulation.[76] Finding the predominant purpose for using an algorithm will not always be straightforward. Athena, for example, challenged the SEC's allegations that it engaged in fraudulent activity: "While Athena does not deny the Commission's charges, Athena believes that its trading activity helped satisfy market demand for liquidity during a period of unprecedented demand for such liquidity."[77] A court might agree. Companies, learning from Athena, can be more circumspect in their e-mails.[78]

A third route may involve the use of market or sector investigations. This approach may help the agencies better understand the new dynamics in algorithm-driven markets and the magnitude of any competitive problems. In some jurisdictions, like the United Kingdom, market investigation laws also provide for a wide scope of behavioral and structural remedies.[79] Following an investigation the agency may benefit from a flexible

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day. The firm implemented additional algorithms known as "Collars" to ensure that Athena's orders received priority over other orders when trading imbalances. These eventually resulted in Athena's imbalance-on-close orders being at least partially filled more than 98 percent of the time. Athena's ability to predict that its orders would get filled on almost every imbalance order allowed the firm to unleash its manipulative Gravy algorithm to trade tens of thousands of shares right before the close of trading. As a result, these shares traded at artificial prices that NASDAQ then used to set the closing prices for on-close orders as part of its closing auction. Athena's high-frequency trading scheme enabled its orders to be executed at more favorable prices.

[74] U.S. Securities and Exchange Commission, Administrative Proceeding File No. 3-16199, para. 34.

[75] *Id.*, para. 36

[76] Peter J. Henning, *Why High-Frequency Trading Is So Hard to Regulate* New York Times (20 October 2014), http://dealbook.nytimes.com/2014/10/20/why-high-frequency-trading-is-so-hard-to-regulate/.

[77] Steve Goldstein, *High-Frequency Trading Firm Fined for Wave of Last-Minute Trades* Market Watch (16 October 2014), http://www.marketwatch.com/story/high-frequency-trading-firm-fined-for-wave-of-last-minute-trades-2014-10-16.

[78] Moreover, evidence of intent will likely be mixed when each firm has valid independent business reasons to develop and implement a pricing algorithm. After all, the first firm to use the pricing algorithm could not be accused of colluding, as the market was likelier less transparent, and rivals could not match the speed of the first mover's price changes.

[79] The U.K. Competition and Markets Authority, for example, can initiate market investigations, gather and appraise evidence, and, where necessary, impose structural or behavioral remedies. Competition Commission, *Guidelines for Market Investigations: Their Role, Procedures, Assessment and Remedies,* CC3 (Revised) (April 2013), https://www.gov.uk/government/uploads/system/uploads/attachmen_data/file/284390/cc3_revised.pdf (adopted by the CMA Board); Algorithms and Collusion – Note from the United Kingdom, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)19, at 11 (30 May 2017).

tool box that is unavailable through other means. The Italian competition authority, for example, noted how it has launched—with the Italian Data Protection Authority and the Italian Communications Authority—a market study on big data, including the various possible competitive implications linked to the rise of algorithms.[80]

Finally, merger review, which in recent decades in the U.S. has focused on unilateral effects,[81] can focus on challenging mergers in industries where tacit collusion is a significant risk.[82] This may require, as the OECD and we recommend, the agencies to consider lowering their threshold of intervention and investigate the risk of coordinated effects not only in cases of three to two mergers, but potentially also in four to three or even in five to four, and to reconsider the approach to conglomerate mergers when tacit collusion can be facilitated by multimarket contacts.[83]

VII. NEW DIMENSION: ARTIFICIAL INTELLIGENCE AND COLLUSION

Algorithmic tacit collusion becomes even more complex when one considers the possible use of neural networks to detect and react to price changes. The significance of Artificial Intelligence to our discussion is notable when considering the *capacity* to engage in tacit collusion, the ability to *detect* it and the ability to *establish liability* for the action.

A. Capacity

Let us begin with consideration of AI's capacity to foster tacit collusion. Of relevance are recent developments in Artificial Neural Networks, also known as "Deep Learning" which aim to mimic the brain's cognitive and computation mechanisms. These complex networks consist of a large number of computation units (neurons), interconnected across several layers.[84] They have already contributed to significant advances in solving

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[80] Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 10 (2 June 2017).

[81] *See, e.g.*, Malcolm B. Coate, *The Merger Process in the Federal Trade Commission from 1989 to 2016* Working Paper (28 Feb. 2018), available at: http://dx.doi.org/10.2139/ssrn.2955987 (identifying for FTC mergers a trend toward unilateral effects analysis and increase in efficiency findings after 1994, although dropping for challenged mergers after 2004).

[82] Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 9 (14 June 2017); Algorithms and Collusion – Note by the United States, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)41, at 6 (26 May 2017); Algorithms and Collusion – Note from the United Kingdom, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)19, at 11 (30 May 2017).

[83] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 40 (16 May 2017).

[84] A. Ittoo, L.M. Nguyen and A. van den Bosch, *Text analytics in industry: Challenges, desiderata and trends* 78 Computers in Industry (2016), available at http://www.sciencedirect.com/science/article/pii/S0166361515300646 or http://dx.doi.org/10.1016/j.compind.2015.12.001.

some of the harder, longstanding challenges for the AI community thus far. By 2017 they have matched or surpassed human performance in various tasks, such as identifying malignant tumors in breast cancer images, image labeling, speech recognition and language translation.[85] Their rapid self-improvement has already resulted in instances in which they evolved beyond recognized human-like decision-making.

An AI program, that its developers at Carnegie-Mellon University called "Libratus," recently defeated several top poker players. This achievement becomes even more impressive when considering the following. First none of Libratus's algorithms were specific to poker. As one of the developers told the press, "We did not program it to play poker. We programmed it to learn any imperfect-information game, and fed it the rules of No-Limit Texas Hold'em as a way to evaluate its performance."[86] The AI program learned the optimal strategy. Second, Libratus' playing style was unlike a human's. The human players could not always identify the computer's dominant strategy. What seemed like bad moves by the computer actually turned out to be good moves.[87] And the computer's strategies seemingly varied hand-by-hand. Third, the computer's strategies evolved day-by-day. When the humans found weaknesses in the computer's play, the players could not quickly exploit these weaknesses. The computer already prioritized identifying and correcting these holes.[88] After 20 days of playing poker, Libratus won decisively.

Another example involves Google's AlphaGo algorithm, which defeated the world's best Go player in a 2017 game. Humans have played Go, which is noted for its myriad possible moves, for centuries. Noteworthy wasn't that the best player was defeated. Rather Go players have praised the algorithm's ability "to make unorthodox moves and challenge assumptions core to a game."[89] The world's best player, after being defeated, noted that "Last year, it was still quite humanlike when it played, but this year, it became like a god of Go."[90]

Deep Learning is often used in conjunction with another paradigm, known as Reinforcement Learning, which prescribes how agents should act in an environment in order to maximize future cumulative reward. The combination of Deep Learning and Reinforcement Learning is promising. It heralds the emergence of algorithms "ingrained" with advanced human cognitive abilities, such as playing Atari videogames and more

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[85] Yun Liu et al., *Detecting Cancer Metastases on Gigapixel Pathology Images*, https://drive.google.com/file/d/0B1T58bZ5vYa-QlR0QlJTa2dPWVk/view (in identifying for breast cancer patients whether the cancer has metastasized away from the breast, a trained algorithm could review large expanses of biological tissues, and automatically detect and localize tumors as small as 100 ×100 pixels in gigapixel microscopy images sized 100, 000×100, 000 pixels, with a rate of eight false positives per image, and detecting 92.4 percent of the tumors, relative to 82.7 percent by the previous best automated approach, and a 73.2 percent sensitivity for human pathologists); Y. Le Cun, Y. Bengio and G. Hinton, *Deep Learning – Review* 521 Nature (2015), available at http://www.nature.com/nature/journal/v521/n7553/pdf/nature14539.pdf or http://dx.doi.org/10.1038/nature14539.

[86] http://www.csmonitor.com/Technology/2017/0204/Bot-makes-poker-pros-fold-What-s-next-for-artificial-intelligence .

[87] https://www.youtube.com/watch?v=jLXPGwJNLHk.

[88] *Id.*

[89] Paul Mozur, *Google's AlphaGo Defeats Chinese Go Master in Win for A.I.* New York Times (23 May 2017).

[90] *Id.*

importantly, beating the human champion at the Go game, considered as one of the AI holy grails.[91]

For tacit collusion, the enhanced analytical capacity and the ability to adapt to changing market reality may enable a more stable and refined equilibrium to be established. Further, one may note how the use of neural networks may impact on the ability to establish liability for the action of the algorithm.

B. Liability

In a simple scenario using today's technology, one could envisage the human operator embedding the tacit collusion model into the algorithm. Although there is no anticompetitive "agreement" among rivals, the human involvement, if one opts to condemn that action, may be relatively easy to detect. But, as noted above, the future heralds more advanced technologies that will be able to act independently, with little or no human input. The algorithm is not programmed to tacitly collude. Programmed with basic game theory, the algorithm, like the one that defeated the world's best poker players, will identify the dominant strategy on its own to maximize profits.

A recent experiment—conducted in Google's advanced Deep Mind neural network—set to identify the dominant strategy that Deep Mind will deploy.[92] Interestingly, in an environment with limited resources Deep Mind deployed aggressive strategies, in an effort to win. However, when collaboration was deemed more profitable (Wolfpace game) two neural agents learned from experimenting in the environment and collaborated to improve their joint position. It will be interesting, as the literature and technology evolve, to see whether the Wolfpace scenario foreshadows the algorithmic tacit collusion scenarios where computers on their own migrate to conscious parallelism as their dominant strategy.

If so, can companies be blamed if their smart algorithms subsequently and independently identify the benefits of interdependence under the tacit collusion scenarios? Suppose, unlike the developers of *Gravy*, the company did not program its algorithm to manipulate the market. Nonetheless as the market dynamics evolve, the algorithm learns that the dominant rational strategy is tacit collusion. To what extent can the company be liable for its self-learning algorithm's actions? And what checks and balances could one impose to prevent machines from changing market dynamics?

The Russian Federation acknowledged these difficulties: "while using the available tools of antitrust regulation and methods of proof, competition agencies face a number of difficulties, including in determining the responsibility of computer engineers for programming machines that are 'educated' to coordinate prices on their own."[93] The

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[91] https://research.googleblog.com/2015/02/from-pixels-to-actions-human-level.html.

[92] Joel Z. Leibo and others, *Multi-agent Reinforcement Learning in Sequential Social Dilemmas*, https://storage.googleapis.com/deepmind-media/papers/multi-agent-rl-in-ssd.pdf; Also see short interview with Joel Z. Leibo, the lead author on the paper on: http://www.wired.co.uk/article/artificial-intelligence-social-impact-deepmind.

[93] Algorithms and Collusion – Note by the Russian Federation, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)22, at 4 (15 May 2017); see also Algorithms and Collusion – Note from Italy, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)18, at 10 (2 June 2017) ("More

European Commission, likewise, noted how more autonomous decision-making may "conflict with the current regulatory framework which was designed in the context of a more predictable, more manageable and controllable technology."[94] The Commission recommended clarifying and, if necessary, adapting the legislative framework.[95] Among the legal approaches under consideration are a strict liability regime; a liability regime based on a risk-generating approach (whereby "liability would be assigned to the actors generating a major risk for others and benefitting from the relevant device, product or service"), and a risk-management approach (whereby "liability is assigned to the market actor which is best placed to minimize or avoid the realisation of the risk or to amortize the costs in relation to those risks").[96] Ultimately, for the Commission, "humans – and, through them, legal entities – must be held accountable for the consequences of the algorithms they choose to use, including in the area of competition policy."[97]

One significant obstacle with a risk-based approach for algorithmic tacit collusion is our ability to understand the magnitude and likelihood of risk and the actuality of harm. When a self-driving car hits a human, the harm is clear. But antitrust enforcers (even with an attractive leniency policy) have had a hard time detecting *express* collusion. Detecting tacit collusion is often more difficult (especially when interdependence can appear in competitive markets). Like the human players against Libratus or AlphaGo, divining a pricing algorithm's strategy may prove even more difficult.

As EU Commissioner Vestager noted, "[t]he trouble is, it's not easy to know exactly how those algorithms work. How they've decided what to show us, and what to hide. And yet the decisions they make affect us all."[98] Likewise, the U.K. competition authority recognized the "complexity of algorithms and the consequent challenge of understanding their exact operation and effects can . . . make it more difficult for consumers and enforcement agencies to detect algorithmic abuses and gather relevant evidence."[99] Significant

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complex challenges for the Authority and the Courts could arise in scenarios where algorithms are self-learning and therefore capable of recognizing mutual interdependency and readapting behaviour to the actions of other market players, without inputs from humans. In particular, the most difficult question is under which conditions antitrust liability can be established in situations where the links between the algorithms and the human beings become more blurred: in such cases determining the liability will depend mainly on the facts at hand.").

94 European Commission, Commission Staff Working Document on the free flow of data and emerging issues of the European data economy Brussels, 10.1.2017 SWD(2017) 2 final, at 43.

95 *Id*.

96 *Id*., at 45. As a complement to the above, the Commission also is entertaining voluntary or mandatory insurance schemes for compensating the parties who suffered the damage.

97 Algorithms and Collusion – Note by the European Commission, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)12, at 2, 9 (14 June 2017) (noting that "firms involved in illegal pricing practices cannot avoid liability on the grounds that their prices were determined by algorithms. Like an employee or an outside consultant working under a firm's 'direction or control', an algorithm remains under the firm's control, and therefore the firm is liable for its actions.").

98 Algorithms and Competition, Bundeskartellamt 18th Conference on Competition, Berlin, 16 March 2017. https://ec.europa.eu/commission/commissioners/2014-2019/vestager/announcements/bundeskartellamt-18th-conference-competition-berlin-16-march-2017_en.

99 Algorithms and Collusion – Note from the United Kingdom, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)19, at 12 (30 May 2017).

is the ability of Deep Learning to adjust to a changing environment and engage in cognitively intensive tasks. As such they form a superior tool to determine market strategy in a changing environment.[100] Indeed, some studies have already highlighted the potential of simpler, basic ANN for dynamic pricing.[101] Another noteworthy characteristic is their ability to learn from experience.[102] This alleviates the need for prior "hand-crafted" knowledge fed in by humans in order to learn a perceptual representation of the world. The self-learning nature enables them to untangle underlying factors in data and to adjust their learning process so that they progressively improve their performance until achieving the desired outcome.[103] For instance, AlphaGo, Google's Deep Learning-based Go champion, and Libratus learned to discover new strategies.

Vestager commented on this challenge. While competition enforcers need not be suspicious of everyone who uses an automated system for pricing, they nonetheless "need to be alert."[104] On a positive note, Vestager's comments make clear that autonomous machines can play a greater role in our markets and lives and some accountability (or compensatory) measure must exist to promote an inclusive economy. The challenge is in adapting the legislative framework so that citizens can trust and benefit from this technology while enabling the industry to "lead and capture the opportunities arising in this field."[105]

C. Detection

In an environment in which online prices are determined by algorithms and their mechanism is complex, enforcers will unlikely trace the steps taken by algorithms and unravel the self-learning processes. If deciphering the decision-making of a deep learning network proves difficult, then identifying an anticompetitive purpose may be impossible.

Even if one resolves the challenges of liability, another problem may emerge—to identify that the market price is indeed the result of tacit collusion and not the competitive price. An interesting consequence of algorithm-driven tacit collusion is the difficulty in identifying the counterfactuals—in other words, the competitive position absent the industry-wide use of pricing algorithms.

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100 http://www.cs.stir.ac.uk/~lss/NNIntro/InvSlides.html.

101 T. Ghose and T. Tran, "A dynamic pricing approach in e-commerce based on multiple purchase attributes", in *Proceedings of the 23rd Canadian Conference on Advances in Artificial Intelligence, Lecture Notes in Computer Science,* vol. 6085 (2010), available at https://link.springer.com/chapter/10.1007/978-3-642-13059-5_13.

102 http://www.cs.stir.ac.uk/~lss/NNIntro/InvSlides.html.

103 D. Castelvecchi, *Can we open the black box of AI?* 538 Nature (2016), available at http://www.nature.com/news/can-we-open-the-black-box-of-ai-1.20731 or http://dx.doi.org/10.1038/538020a.

104 Margrethe Vestager, Speech: *Algorithms and Competition*, at the Bundeskartellamt 18th Conference on Competition, Berlin, 16 March 2017, available at: https://ec.europa.eu/commission/commissioners/2014-2019/vestager/announcements/bundeskartellamt-18th-conference-competition-berlin-16-march-2017_en. She added that businesses "need to know that when they decide to use an automated system, they will be held responsible for what it does. So they had better know how that system works." *Id*.

105 European Commission, Commission Staff Working Document on the free flow of data and emerging issues of the European data economy Brussels, 10.1.2017 SWD(2017) 2 final, at 43.

In practice, it may be difficult for an enforcer or regulator to conclude to what extent the current prices reflect the "natural" outcome of market forces or the byproduct of tacit collusion, which the algorithms "artificially" enhanced or fostered. In a market dominated by algorithms, absent a natural experiment or counterfactual (such as a similar market without algorithms), enforcers may not readily discern whether the market price is the result of artificial intervention or natural dynamics: the dynamic price may be the only market price.

One answer may involve auditing the algorithm. Under an auditing regime, the agency will assess whether an algorithm was designed to foster a change in the market dynamics. This approach resembles pre-merger review—where the agency predicts whether the proposed merger may substantially lessen competition or tend to create a monopoly. Accordingly, algorithms could be activated in a "sand box" where their effects will be observed and assessed.

Auditing at times can predict anticompetitive outcomes. But based on our discussions with computer scientists, auditing is not as simple as opening the hood of the car to see what is causing the irregularity. To begin with, it may be hard to establish whether the algorithm submitted for audit is the one used in the marketplace. This is not simply a bait-and-switch by the firms. Rather through machine-learning, trial-and-error, and market changes, the algorithm itself evolves. Similarly, the ease with which an audited algorithm may be amended and set different optimization goals could undermine effective scrutiny. Other challenges include the sheer number of algorithms which would require scrutiny, the high level of expertise required to assess their effects, the ability to identify credible counterfactuals, and the barriers associated with commercial secrecy. Lastly, in the case of neural networks, it may be impossible to effectively audit a complex system and determine its likely effects.

Some challenges may be addressed by shifting the burden to the companies and imposing on them a duty to comply with a set of guidelines and principles of compliance by design. One could imagine the creation of an industry code of practice, which companies must follow when designing the algorithms. Random inspections perhaps could increase deterrence and compliance.

VIII. CONCLUSION

With the industry-wide use of computer algorithms and artificial intelligence, we may witness algorithmic tacit collusion in markets where collusion previously would have been unstable. The OECD in 2017 reached the following two conclusions:

> Firstly, algorithms are fundamentally affecting market conditions, resulting in high price transparency and high-frequency trading that allows companies to react fast and aggressively. These changes in digital markets, if taken to a certain extent, could make collusive strategies stable in virtually any market structure. Secondly, by providing companies with powerful automated mechanisms to monitor prices, implement common policies, send market signals or optimise joint profits with deep learning techniques, algorithms might enable firms to achieve the same outcomes of traditional hard core cartels through tacit collusion.[106]

[106] Algorithms and Collusion – Background Note by the Secretariat, submitted for the OECD Competition Committee Hearings on 21–23 June 2017, DAF/COMP/WD(2017)4, at 49–50 (16 May 2017).

Our collusion scenarios are part of several anticompetitive outcomes, which necessitate re-calibrating our enforcement strategies. As our book *Virtual Competition* explores, big data and big analytics can enable some online sellers to engage in behavioral discrimination. We will also see the rise of a new frenemy dynamic whereby many companies become increasingly dependent upon the beneficence of the dominant super-platforms, namely Google, Apple, Facebook and Amazon.

But virtual competition is not necessarily bleak. As *Virtual Competition* discusses, the transformative innovations from machine-learning and big data can lower our search costs (whether finding a raincoat or parking spot), lower entry barriers, create new channels for expansion and entry, and ultimately stimulate competition. But these technological improvements are not automatic. Much depends on how the companies employ the technologies and whether their incentives are aligned with our and societal interests.

Nor will data-driven online markets necessarily correct themselves. Nor will the anticompetitive effects be obvious. Dominant firms can be a step ahead in developing sophisticated strategies and technologies that distort the perceived competitive environment. Antitrust, while not obsolete, may prove unwieldly at times to apply even with a compelling theory of harm. Indeed, without evidence of anticompetitive agreement or intent, an engaged competition agency will still be hamstrung. So our current antitrust laws may not deter some of the collusion scenarios we identify.

Accordingly, businesses (and competition authorities) must better understand how the rise of sophisticated computer algorithms and the new market reality can significantly change our paradigm of competition—either for the better or worse. Legal safeguards should be explored to promote competition on the merits. Otherwise, we will likely experience more durable forms of collusion (beyond the enforcers' reach), more sophisticated forms of price discrimination, and an array of abuses by data-driven monopolies that, by controlling key platforms (like the leading operating system for smartphones), can dictate many companies' (and our economy's) oxygen supply.

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